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ABSTRACT

The purpose of this report is to see what the literature has to say about motivation and group interactions, both with and without the assistance of computers. The ultimate purpose is to examine in detail how the emerging ideas can be used to enhance the teaching and learning of arithmetic using computers. This report is divided into the following sections: motivation, teaching, and small group interaction. Each section contains general considerations and summaries of the major research papers of interest. Topics covered in these papers include curiosity, fantasy or play, interest of students, attitudes of students, teaching methods, discovery learning, Piagetian and Neo-Piagetian methods, evaluation of teaching methods, problem solving, knowledge processing, goal construction, and cooperative learning. (KR)

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A Report on Studies of Motivation, Teaching and Small Group Interaction with special reference to Computers and to the Teaching and Learning of Arithmetic.

Michael E. Fox
March 1988

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CITE Report No. 31

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A REPORT ON STUDIES OF MOTIVATION TEACHING and SMALL GROUP INTERACTION With special reference to Computers and to the Teaching and Learning of Arithmetic [1]

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[1] Open University, Center for Information Technology in Education, Technical Report No. 31. Report date 15 March 1988. This work was done as part of Alvey project IKBS 063, 'An Intelligent Computer Tutor For Arithmetic'.

INTRODUCTION

The purpose of this report is to see what the literature has to say about the topics in the title, both with and without the assistance of computers. The ultimate purpose is to see in detail how the emerging ideas can be used to enhance the teaching and learning of arithmetic using computers and everything selected has been done with this in mind. The ultimate purpose of showing how the emerging ideas could be applied is not attempted here although incidental comments on this aspect do appear and the conclusions at the beginning of each of the three main parts are an indication where this may start. Thus the form of the report and is not a review with a full synthesis with conclusions about how to design educational software for arithmetic but rather sources are summarized with a view to doing this at a later date. As a result of this there is some overlap between the main parts.

In selecting the literature I have thrown the net wide rather than deep since my need is to find main ideas from any source that might be useful in a classroom setting. However the references will supply a great deal of further reading. The report attempts to cover literature published up to the end of 1986.

Acknowledgments

To Professor Tim O'Shea and Dr. Ann Floyd who as investigators in this Alvey project gave the author the wherewithal to prepare this report. To Dr. Alistair Edwards and Dr. Diana Laurillard who read the manuscript and made many useful suggestions.

MOTIVATION

Inspection of a couple of recent reviews of research into maths education, (Bell et al 1985, Dickson et al 1984) reveals a dearth of material containing details of motivation in learning maths at a level that would give specific help in designing educational software. One review, (Bishop and Nickson 1983) , refers to children's and teachers' attitudes in relation to maths but does not address motivation directly.

Skemp (1979) would like to discard the idea of motivation from the study of teaching and learning. He argues that as far as teachers are concerned it is better not to think in terms of motivation at all but of co-operation. Motivation and motivating lead us to think in terms of what is done to an individual rather than what is done by an individual with a choice.

Nevertheless there remain a number of potentially useful recent papers which explicitly consider motivation in teaching and learning. They make clear a number of important concepts and heuristics that could be used in the design of educational software and although they do not cite each other they appear to reveal an important concensus.

General Conclusions

These are conclusions emerging from the papers summarized here which I believe can form a tentative basis for thinking about children's motivation and computers.

1. The central concept in all three papers discussed in detail is that of the significance of information . Three kinds can be distinguished. First perceptual significance, which in terms of a computer would include a cursor or a colour used for a particular purpose. Here the information received simply serves to attract attention. Second epistemic or cognitive significance, which refers to meaning , such as the mathematical significance of a list of numbers e.g. a list of primes. Third emotional significance such as that which may be found in an adventure game where the player identifies with the hero or heroine or where a player is excited by the goal of an arcade game in which s/he exterminates all the aliens.

2. What is actually found by a person to be informationally significant varies from the universally human (e.g. death themes in stories) to the idiosyncratic (e.g. listening to the sound of your own voice - poor spellers learn to spell more quickly if words are spelt using the learners voice). Because most information is not of similar significance to everyone it is unlikely that every user will like a particular computer activity.

3. Provided the computer activity is appropriate for the user's knowledge, information can be manipulated or structured to create cognitive conflict which may motivate the user to explore and integrate the new information into their understanding. Surprises, rule or schema violations, missing information can all serve to create this conflict, Mallone (1981).

4. A learning activity which, say, has mainly epistemic aims needs a structure which stresses this and does not over-emphasize the other two kinds of information. Thus what is important should be interesting and what is interesting should be important though as a practical matter the importance may be merely instrumental in drawing attention to an epistemic aspect, Hidi and Baird (1986).

5. Interventions (including feedback) also need to take account of these kinds of informational significance since the interventions themselves are information.

6. Computer games seem to derive much of their effect on motivation from the presence of a goal. A good goal is personally meaningful, at the appropriate level of difficulty and and reaching it is uncertain. Uncertainty can be created in various ways e.g. by hiding information which is selectively revealed as the game progresses, Mallone (1982).

7. Finally there is a social aspect to motivation but this is left to the group interaction part of this report.

SUMMARIES OF THE MAIN PAPERS OF INTEREST

MALLONE

Mallone (1981) examined computer games with a view to applying their motivational qualities to educational activities on the computer. He grouped the motivational qualities under three headings. Challenge, curiosity (similar to interest) and fantasy. He tried to be specific about just what you do when designing with these ideas in mind. His findings are given below. Additional details in Mallone (1980).

CHALLENGE

The single feature that correlated most strongly with children's preference for a game was whether or not it had a goal. Good goals were personally meaningful e.g. a character to identify with, something for the player to destroy, a score to

beat. In more complex games goals are generated as part of the activity e.g. as part of LOGO. In these cases goals should be easy to generate at the appropriate level of difficulty. There should be performance feedback to show how well any goal is being achieved.

The example goals noted above can all have an uncertain outcome and this is the second key to a good goal. Obviously there is no challenge if the outcome is certain - either way. Challenge can be created by appropriate difficulty level, hiding information and randomness.

Hiding information which is later selectively revealed creates uncertainty and probably corresponds to the omission design principle in Burkhardt et al (1985). Randomness, which occurs in adventure games has the same effect. Thus the difficulty of achieving the goal must be appropriate for the individual. Difficulty may be varied by the computer, chosen by the learner or determined by the opponent's skill - hence to need to match players. Sub-goals which are steps on the way to a main goal are no different in this respect than activities with single goals. Goals may offer variable amounts of success as in achieving something faster or better. In Mallone's brief discussion of particular games he makes an interesting. comment about how the players can subtly choose their own level of difficulty.Thus in the (non-computer) game of tag the chaser can choose who to chase and the chased can choose how close to go to 'it' and in that way every player has some choice in difficulty level. (DeClark in Kamii(1985) gives many examples of children apparently choosing their own difficulty level in mathematical games.)

CURIOSITY

Mallone suggests a theory of curiosity that brings in the three qualities of completeness, consistency and parsimony. The absence of one or more of these qualities in a computer game causes a state of cognitive conflict and makes the player curious. Mallone distinguishes cognitive (epistemic) and sensory (perceptual) curiosity.

An environment that stimulates curiosity is neither too simple nor too complex. It is novel and surprising but not completely incomprehensible.

Surprising feedback engages curiosity. Constructive feedback helps learners to see that knowledge is incomplete or inconsistent or not parsimonious.

FANTASY

For Mallone fantasy appears to be synonymous with play where the stress is on the correspondence between the play and real situations. He distinguishes extrinsic fantasy (e.g. playing hangman while learning to spell) from intrinsic fantasy where the fantasy and what should be learned are naturally related, (e.g. shopping to learn arithmetic).

There are important personal differences in fantasies liked and he gives the example of a darts and arithmetic game which was less liked by girls than boys. In this game a player estimates the position of a balloon on a number line by 'throwing' a dart from a position corresponding to the estimated position. If the dart bursts the balloon the estimation was accurate.

KELLER

The only recent review of the application of the results of motivation research to teaching as a whole is Keller (1983). This author has synthesized the relevant research into a set of heuristics for teaching, some of which might be applied to the design of computer based activities. The synthesis is under four basic headings; interest, relevance, expectancy and outcomes. The heuristics suggested are not prescriptive but are reasonably specific.

INTEREST

This is perhaps best summarized with the slogan 'arouse and sustain'. Meaning that a teacher should first stimulate interest and then sustain it through an activity.

An important distinction is made between the perceptual aspect of interest, such as a sprite on a computer screen and the more important epistemic aspect where interest relies on the meaning of some object or event etc. These aspects may be combined e.g. perceptual combined with epistemic in a flashing numerical answer. The first few heuristics below are concerned more with the perceptual aspect while the latter ones are concerned more with the epistemic aspect.

Teachers are cautioned not to overdo arousal and to remember that it should not get in the way of learning.

Heuristics for creating interest

1. To increase curiosity, use novel, incongruous, conflicting and paradoxical events. Attention is aroused when there is an abrupt change in the status quo.

2.To increase curiosity, use anecdotes and offer devices for injecting a personal, emotional element into otherwise purely intellectual and procedural material.

3.To arouse and maintain curiosity, give people the opportunity to learn more about things they already know about or believe in, but also give them moderate doses of the unfamiliar and unexpected.

4.To increase curiosity use analogues to make the strange familiar and the familiar strange.

5.To increase curiosity, guide students into a process of question generation and inquiry.

RELEVANCE

Sustained motivation requires the learner to perceive that important personal values are being met by the learning situation. Two categories are relevant here (a) the general personal values of achievement of power and of affiliation and (b) instrumental value, (only achievement and instrumental value is further discussed here, affiliation and power are left to the group interaction part of this report) .

Achievement is enhanced when it is a direct consequence of one's own effort. The appropriate goal may depend on the individual, hence children should be able to choose their own difficulty level.

Heuristic for making learning relevant

To enhance achievement-striving behaviour, provide opportunities to achieve standards of excellence under conditions of moderate risk.

Instrumental value refers to the increase in motivation to accomplish an immediate goal when it is perceived to be a required step for attaining a desired future goal. It is therefore important for learners to see the connection between what is being learnt and its wider importance.

EXPECTANCY

This means the attitudes towards success and failure that are brought to a piece of work. There are two aspects, expectations of others and expectations of oneself, only the latter is to be considered here. Motivation tends to increase as expectancy of oneself increases.

Heuristics for raising personal expectancy.

1. Increase expectancy for success by increasing experience of success.

2. Increase expectancy for success by indicating the requirements for success.

3. Increase expectancy for success by offering personal control of success.

4. Increase expectancy for success by helping students to connect success to personal effort and ability.

OUTCOMES

These are factors that influence the satisfaction that may accompany goal accomplishment and the motivation to continue pursuing similar goals.

To develop and maintain personal motivation for a given activity use reinforcement but do not do it in such a way that the controlling influences detract from intrinsic satisfaction. (In general extrinsic reinforcement may reduce intrinsic motivation.) Reinforcement should relate to the nature of the task to be reinforced (task endogenous vs. task exogenous reinforcement). Thus if money is part of the task then provide reinforcement in money but don't if it isn't

Heuristics to promote good outcomes

1.To maintain intrinsic satisfaction with instruction use task-endogenous rather than task-exogenous rewards.

2.To maintain intrinsic satisfaction with instruction use unexpected non-contingent rewards , e.g. at the end of a successful piece of work comment on why it's well done rather than tying rewards to specific criteria such as a clear marking scheme known to the learner.

The exception to this is lerning dull facts. Here extrinsic rewards such as marks are less likely to have a negative effect .

3.To maintain intrinsic satisfaction with instruction use verbal praise and informative feedback rather than threat, surveillance and external performance evaluation.

4.To maintain quantity of performance use motivating feedback following elements of work on a task.

5.To improve the quality of performance provide formative (corrective) feedback when it will be immediately useful, usually just before the next opportunity to practice.

HIDI and BAIRD

Hidi and Baird (1986) reviewed work on interestingness in discourse, especially in stories and textbooks. Broadly speaking the authors conclusions about stories are similar to many of those of Mallone in relation to computer games.

The authors distinguish two types of interest .First knowledge triggered interest as when one part of a text is seen to relate to another and second value triggered interest which arises, say from an event in a story which is personally involving . They suggest interest is an affect in which a person responds to a situation of special significance. The source of the special significance can vary a great deal, producing different types of interest. For example dissonant information may lead to surprise, novelty, resulting in the type of interest usually associated with reading stories; in other cases interest that may be considered to be emotional is created by information relevant to important life themes, e.g. death, violence. What is central to the response of interest is that a person is compelled to increase intellectual activity to cope with the greater significance of information.

The significance which produces interest may vary from the universal to the idiosyncratic.

The notion of informational significance draws attention to a wide range of sources of interest.

Informational significance and the actual importance of information may or may not correspond.

DECLARK

DeClark in Kamii (1985), chapter 10, gives an account of how young children play mathematical games. The account abounds with examples of mathematical games in which goals, choice of personally meaningful fantasy, the choice of appropriate difficulty levels by children themselves and many other motivational features can be discerned.

RIDGEWAY et al

Ridgway et al (1983a & 1983b) gives examples of computer games in the classroom that were popular and considered to be highly motivating.

TEACHING

Here I have selected recent literature that I think contains empirically tested ideas which may be applicable to computer based teaching, but I have not reviewed papers specifically concerned with computers.

General Conclusions

The general tenor of the literature is to advocate learning for understanding. Overall two main goals emerge to guide the design of educational software.

1. Activities should be designed so that most children should, for most of the time feel they understand enough to want to continue using them.

   Specifically, in the short term, learning for understanding can be more demanding than rote learning. In maths in particular, anxiety is easily created by failure. Thus in order to make the extra effort always worthwhile and to prevent anxiety arising to any great extent the demands and responses of the activities should regularly lead to understanding and hence to regular success.

2. In order to motivate learning for understanding we must, as far as possible, make trying to understand important to a child and we should monitor that understanding.

   This is by way of contrast with say, simply rewarding correct answers which might be obtained without understanding.

The teaching method suggested by these papers is obvious and falls into three parts:-

(a) prerequisites and testing for their achievement by learners,
(b) structuring the teaching material,
(c) teach using appropriate illustrations, explanations, questions, etc.

Also suggested by the papers but not so obvious is :-

(i) the cognitive conflict method of teaching advocated and
(ii) the filling of these parts (a) to (c) with detailed empirically supported knowledge .

This knowledge, it is claimed, should make teaching much more thorough and much quicker.

The recommended filling out is summarized below.

(a) Prerequisites and testing for their achievement

There appears to be little research work little information on this topic. Although exhortations to find and check their fulfilment are commonplace some work indicates exact delineation of an individual's starting knowledge is not very helpful, (Resnick(1987), Denvir and Brown (1986b)). Though clearly some general prerequisites will be essential in a particular case.

(b) Structuring the material

A basis for structuring the material in arithmetic which is especially worthy of consideration because of its detailed nature and results claimed is the method based developed by Case and his students. The ideas have grown from a base of Piagetian ideas and the method is sometimes called Neo-Piagetian .

Essentially this consists of carrying out observations on children learning the material in order to create an empirically validated hierarchy of concepts and skills etc. and their associated difficulties. The material is then structured using the hierarchy with small steps that minimize working memory demands. Automatization is ensured by providing practice, revision and repetition of the teaching sequence. Alternative embodiments[2] are used to generalize understanding including problems in context.

The Case method assumes that in the structuring of material key concepts are more important than procedures and that context and goals are also important. This structuring enables the teacher to understand and control the child's difficulties. Collins and Stevens (1983) also have some empirically based suggestions to aid structuring e.g. more important factors before less important.

(c) Teach using appropriate illustrations, explanations, questions, etc

In stepping through the material immediate feedback with explanation should always be available. This is suggested both by Case and by Brown and Campione

2.An embodiment is a particular model of a group of mathematical ideas. An embodiment is distinct from a mental representation of the embodiment. The word representation is often used loosely to mean either, but strictly an embodiment is an external representation as opposed to an internal or mental representation.

who contribute the idea of gradually relinquishing teacher control say by moving from demonstration to guided practice to monitored practice. Bell et al(1986) and Collins and Stevens both stress the importance of bringing a child face to face with his/her misconceptions (though Denvir and Karmiloff-Smith(1986) believe this is too much for many children to face and stress the motivating effect of social context in learning). Collins and Stevens offer a number of methods used in discovery learning which could be used to expose misconceptions e.g. vary cases, look for contradictions, Bell and his co-authors(1986) rely on vigorous discussion. Work on analogical problem solving indicates the importance of offering hints and or rules to help with transfer. The value of teaching for metacognitive abilities e.g. summarizing or isolating important points is stressed by Brown and Campione and by Scardamalia and Bereiter. The latter authors also suggest that ways should be found to make these self regulatory actions routine so as to reduce the burden of thought for children. The importance of the metacognitive objective of understanding goals of a particular piece of work is stressed by several authors. This is of course best understood in an appropriate social and functional context of the use of the material to be learned.

BELL et al (1983)

In their review of learning and teaching maths (Bell et al 1983) the chapter on teaching provides a critical appraisal of relevant investigations up to the early eighties.

The subject of the chapter is the choice of methods by which to teach material that has already been selected for teaching. Their general conclusions are quoted below.

'The research to be reported shows that exposition is generally more effective in the short term, but discovery is better for longer-term retention and for transfer to new situations. The analysis of a skill into component sub-skills and the teaching of these cumulatively, with a mastery criterion for progress from each sub-skill to the next, is also shown to be effective. But more effective methods still are those based on 'cognitive conflict'. These see learning as the breaking out of a limited framework of knowledge into a more inclusive one, and this being provoked by meeting situations which appear contradictory in the more primitive framework.'

'Many of the experiments described here achieved spectacular success, and some of the methods developed in them make our usual classroom practices look primitive. But they have generally operated under more favourable conditions than exist in the typical classroom. Nevertheless, there would appear to be substantial benefits to be gained if we could develop some of these methods into classroom form and spread the knowledge of them more widely.'

The main point the reviewers are concerned with throughout is a general trend in the literature that indicates the inadequacy of rote learning and the importance of meaningful learning.

DISCOVERY LEARNING

The claims for discovery learning distilled from the literature by Bell et al are as follows :-

(1) it ensures meaningful learning, since the pre-requisite knowledge must be activated before the discovery activity can progress

(2) it presents situations in the same ways as those in which the learning will need to be used subsequently

(3) it promotes the learning not only of the principle itself but of general strategies for the investigation of problems

Correspondingly if unsuccessfull discovery methods inhibit learning

It is generally assumed that there will be some guidance with the discovery approach, but the closer the guidance the less opportunity a learner has to develop his or her own methods.

Discovery of mathematical generalizations involves empirical and deductive approaches e.g. you can deduce or induce by measuring that the angles of a triangle add up to 180^{o}. It is also possible to discover concepts e.g. concept of a square may be discovered by comparison with other rectangles.

Individuals react differently to the discovery approach or its absence. Extraverts are handicapped by a rule bound approach before they have had a chance to find out for themselves. Highly anxious children do badly under the discovery approach.

Later research has moved away from discovery learning towards a more detailed analysis of learning tasks. Gagné's method of detailed breakdown into sub tasks is noted by Bell and co-authors.

The probable importance of Ausubel's 'advance organizers' is also noted. An advance organizer is an overview to indicate the relationships and importance of what is to be learned.

PIAGETIAN TEACHING METHODS

Piaget's successors have carried out experiments to expose children's natural learning processes by attempting to produce learning by teaching interventions. (Piaget himself aimed to describe development of the intellect, not to investigate the effect of teaching.)

To accelerate learning, teaching should resemble the natural learning process. This requires knowledge of the normal stages of development through which children pass in acquiring the concepts under consideration. In teaching any one concept knowledge of it's prerequisites must be ensured.

The Piagetian method recognises that there will inevitably be breakdowns in learning as the developmental process occurs. Tasks are then designed in which the use of inadequate conceptual schemas leads to a cognitive conflict between the contradictory results of the erring child and the results that would be achieved by a more successful child (the results achieved by the successful child are not necessarily the 'correct' answer but may just be a step on the way). The erring child is then stimulated to seek a resolution of the results which involves restructuring the conceptual system to deal with the task from which the contradiction arose.

This restructuring is essentially a reflective activity not the learning of a skill and as such may or may not involve the manipulation of concrete materials.

The teacher can have confidence in the restructuring when the child can :-

- explain his/her conclusion about the activity
- resist counter arguments
- transfer the knowledge to new tasks differing in small and large ways including changes in context
- retain the knowledge for some weeks.

The Piagetian teaching method produces discovery by the correct analysis of learning and design of activities to reveal misunderstandings. It does not appear to involve guidance and definitely does not involve feedback of results. It should be noted that direct teaching with feedback and repetition can produce as good results even with the strong tests of learning noted above. However this should not thought of as reducing their interest. Piagetian teaching methods are oriented towards the investigation of learning and are not presumed to be better than other methods of teaching though it is hoped that developments of Piagetian ideas may

indeed make a superior teaching method in some circumstances. Examples are given below ; (Case(1985) and Bell et al (1986)).

NEO-PIAGETIAN METHODS

Case and his students (see below) are researching developments of the Piagetian approach. These so called Neo-Piagetian methods differ from Piagetian methods essentially in their explanation of why the general intellectual development of children is age related and similar and slow across many domains. Whereas Piaget speaks of a mechanism of 'autoregulation' of general functions underlying all intellectual development, Case believes (and has experimental results to support it) that the general learning limitations found at different ages are related to a gradual increase in the size working memory (WM). It follows that if tasks can be structured so that they are achievable within the working memory available, more and quicker learning may occur. Adult learning can also be shown to be limited by working memory.

The details of the Case method are given below but the general conclusion of Bell et al is that features added by Case to Piagetian teaching methods may have considerable significance. Case himself describes the results as only fairly successful and the author of this report has not seen replication of this type of work outside his group.

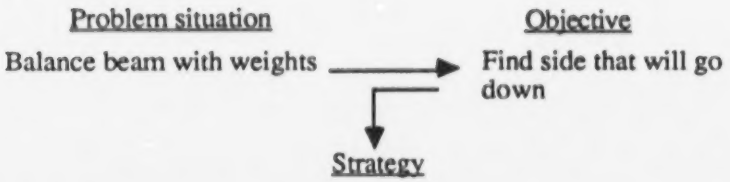
CASE et al

In Case (1985) the author has reviewed ten years of work by himself and his students on his Neo-Piagetian teaching method.

The execution of a task is interpreted as controlled by a mental procedure involving (a) a representation of the problem situation, (b) a representation of the objective to be achieved and (c) a representation of the step(s) for achieving the objective. This is called an executive control structure.

In the case of the Piagetian balance beam (i.e. a simple child's balance beam where weights can be placed at various positions on either side of the fulcrum), gradual improvements in the ability to explain for a given weight distribution which side will go down are ascribed to increasing complexity of the executive control structure as described below.

At age 3-4 children choose the side that looks heavy as the side that will go down. This is interpreted as the simplest executive control structure.



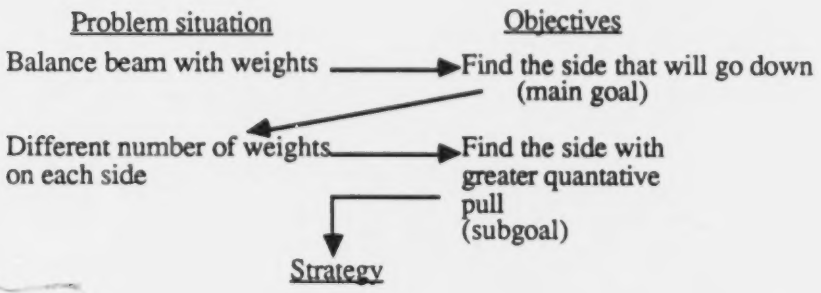
Scan each weight to see which one is heavy.
If so, pick it's side to go down.

Clearly this strategy works in very restricted circumstances only.

N.B. No indication is given by Case of what happens if neither side is heavier.

Age $4^1/_2$ - 6 children quantify the number of weights on each side and pick the side with the greater number.

This is interpreted as a more complicated executive central structure.


Problem situation
Objectives
Balance beam with weights
Find the side that will go down (main goal)
Different number of weights on each side
Find the side with greater quantative pull (subgoal)
Strategy

1. Scan each weight to see if one is heavier, if so pick that side, if not go to 2.

2. Count weights on <u>each</u> side, label the side with the larger number as heavier, return to 1.

(This strategy works in less restricted circumstances.)

Each component of the executive control structure (ECS) now contains an additional element. As a result the main goal must be remembered while processing the sub-goal and the number of weights on the side must be remembered while counting the weights on the other. Case claims that the working memory required is increased. Each set of new elements is called a loop.

A similar analysis is made for further progressive improvements with age in the solution of balance beam problems. This reveals a hierarchy of strategies, from the most simple to the most general. The same age related progression applies to a wide variety of other problem situations.

The question then arises as to what is responsible for enabling improvements to the executive control structure. Experience is important but it is not enough to explain why development takes so long (still not complete at 10 years) and why development occurs at a similar rate across many domains.

Case argues that unless a working executive control structure becomes automatized, additions to the structure will increase demands on working memory. Since working memory size develops slowly and control structures often do not become automatized,the complexity of the ECS that can be executed will often be limited by WM. Hence ability to solve balance scale and other problems will also develop slowly.

This argument leads immediately to the point that provided a task can be organized so that WM is not exceeded then there is no reason to assume that there is a limit to the number of loops that a child can incorporate into pre-existing ECSs'.

This idea is then combined with the generally accepted view of developmental psychologists that progress from stage to stage in learning is best facilitated by presenting the child with tasks one level beyond the current level of functioning.

For the learning to be natural the stages must be specified by studying children's actual behaviour, leading to a hierarchy of ECSs. Each inadequate strategy will lead to error(s), which must also be examined. This leads to the design of a hierarchy of tasks which are used for step by step teaching. Each task is designed to expose the limitations of the oversimplified strategy by enabling the child to check that error(s) do occur when it is incorrectly applied or by being shown some by the teacher. Thus the necessity of applying the next less simplified strategy will become apparent. This new strategy will be both natural and (inevitably?) respect the need to minimize WM. Each task is also designed to minimize WM by minimizing the number of items requiring attention.

At each step the teacher must satisfy him/herself that the previous ECS is thoroughly learnt otherwise the WM minimization will not apply.

At each new level WM demands are further reduced by the teacher emphasizing (at first) important but non-obvious features.

Thus teaching proceeds on the assumption that the pupil's knowledge of what s/he is trying to achieve guides his/her action. Teaching also assumes that key concepts in the pupil's own procedures are more important than the procedures themselves.

The ordering of difficulty and strategies found to be applied may not be obvious, i.e. what is easier or harder for a pupil is not necessarily clear nor are the reasons. Hence investigations and not suppositions are essential and therefore the domain must be amenable to a hierarchical analysis of complexity.

Results from teaching, using this method for learning the balance scale, maze tracing, quantity evaluation, conservation and separation of the effect of two variables, are very encouraging.

The most thorough investigation is that of Gold (1978) on the teaching of proportion. In this work able and below average children were taught either by the Case method or by the standard method for the California school system, a method based on an empirically validated hierarchy of the sort pioneered by Gagné and by the Case method. The results of a delayed post test are given below.

Units = Percentage achieving 13/20 or more

Group	10 - 11 above average ability	12 - 13 below average ability
Standard	33	11
Cagné	78	33
Case	100	100

It should be noted that Gagné (1983) has criticized the Case teaching method on the grounds that there will be both unusual misconceptions and sheer guesses that will not fit into the prearranged schema. In addition there will be teacher misunderstandings of the oversimplified strategy actually used.

The method used by Gold to ensure automatization is very thorough. An embodiment of the concept is first chosen. Then at each ECS level practice problems and revision using simpler problems is provided with teacher explanation as necessary. Then the whole process is repeated for that embodiment. Finally the whole of the above approach is repeated for other embodiments.

BELL et al (1986)

In Bell et al (1986) the results of important research organised at the Shell Centre for Mathematics Education are published. The aims of the research, which is continuing, are to develop a way of teaching which contributes clearly to learning for understanding and to learning for transfer. (This research is at the secondary level.)

The key aspects of the method developed are:-

- identification and exposure of pupils misconceptions which lead to cognitive conflict which is resolved by vigorous discussion.

- conceptual diagnostic tests to help pupils become aware of misconceptions and to enable the teacher to observe progress.

The teaching materials for a particular topic follow the pattern below

- they begin with a rich situation, containing various items of information, with an invitation to consider what further information can be found out from what is given.

- following initial exploration there is focus on a few particular questions which contain important conceptual obstacles.

- questions are posed in such a way as to allow misconceptions to come to the surface (if they exist) and thus to create conflict which can be discussed and resolved.

- then exercises are supplied with built-in feedback of correctness. i.e. the new awareness reached during conflict discussion is put into practice in a situation where pupils know immediately they have made an error and can reconsider their response.

MAJOR TESTS OF THE DIAGNOSTIC TEACHING METHODOLOGY

Three comparative experiments demonstrated the effectiveness of the features of the diagnostic method . The results showed :-

1.The superiority of conflict teaching vs positive only teaching, (i.e. only consider right methods), in the teaching of decimal place value.

Positive only focussed on areas known to cause difficulty but correct concepts and procedures were evolved without explicit discussion of misconceptions.

2.The more vigorous and intensive discussions were associated with greatest progress in the teaching of directed quantities.

3.Greater learning in diagnostic classes compared with teaching by exposition for understanding in the teaching of rates.

The expository method gave rules and guided discovery leading to correct conclusions drawn by the pupil, ie. no conflict.

TESTS OF PARTICULAR ASPECTS OF THE TEACHING METHOD

Tests were carried out to establish the conditions for successful conflict discussion .

Apart from the use of a few critical problems a number of particular types of task were developed which provided a variety of ways of revealing misconceptions, provoking reflection or activating relevant concepts.

-using diagrams
-substituting easier numbers
-games
-making up questions
-group tasks
-immediate feedback

Using Diagrams

Broadly speaking those pupils who need a diagram to help them solve a problem

are those who cannot draw a correct one because they cannot conceptualize the problem in a sufficiently clearl way.

Those who could draw a correct diagram often do not need to because they have the necessary understanding to solve the problem mentally.

However, teaching which used construction of suitable diagrams as a basis for discussion of concepts and relationships did appear successful. The clarification of understanding which results from this often allows solution without drawing diagrams. This suggests that explicit discussion of key concepts is essential. i.e. the value of diagram is when the teacher draws it to aid conceptualization.

Substituting Easy Numbers

It is easier to choose an operation with an easy number as it is quicker to try out and check expectations. 0 and 1 as easier numbers are unhelpful.

It is best to vary numbers in a problem as a means of developing the concept of invariance of quantity relations under change of number.

Games

They engage players in choices involving key concepts and misconceptions and are clearly very powerful learning situations.

If well designed they have elements of checking (either inbuilt or by opponents challenge), self adjustment to the pupil's own level, choice of examples by the pupil and repetition with variety.

Successful games were developed in most teaching experiments.

To achieve the potential value of a game it is necessary to follow it by a discussion focussed on the principle to be learned or misconception to be overcome in which the relevant idea is explicitly articulated by the pupils and the teacher.

Making up questions

this includes several ways of reversing the usual teaching order of teacher asking questions and pupil giving answers.

-pupils generate questions from a situation,
-pupil makes up story from a given calculation. (Possibly in a given context.)

Marking Homework

The pupil marks actual or fictitious homework, stating the nature of the error and offering a positive explanation.

Both making up questions and marking homework are good ways of promoting reflection and discussion, although they are not easy and require perseverance for pupil to get used to them.

Group Tasks

Here the teacher sets critical problems to be tackled by small groups. Class discussion follows .

Immediate Feedback

Yes/no feedback does quickly produce improvements but it needs explanations for progress in understanding.

Example Investigation - Multiplication problems

A numbers and notation approach was compared with problems in context.

The choice of operation, (multiplication, division etc.) in problems given to pupils was found to be heavily influenced by their numerical misconceptions. The question asked in the research was would teaching aimed at removing these misconceptions be more or less effective than teaching whose purpose was to establish the general quantity relations in context, e.g. weight x price = cost.

A number of experiments with classes of secondary school children were carried out.

1. Separate classes were taught, in each only one of the two approaches was used. There was not much progress in choice of operation in either class.

2. The 2 approaches were combined. This produced improvements on price/quantity relations but not much else.

3. Using specially developed material, called Numbers and Notation, the teaching was aimed at numerical misconceptions only. This produced good results on the numerical section of the test but not much effect on choice of operation.

4. Problems were given in context. The teaching aimed at dealing with numerical misconceptions within the context of problems concerning price. This produced

good gains on choice of operation and in numerical questions.

5. Teaching was (a) aimed at numerical misconceptions using the special Numbers and Notation material followed by (b) problems in context. After (a) there were only trivial gains on choice of operation but substantial gains on numerical questions. After (b) there were substantial gains in choice of operation questions and further substantial gains in numerical questions .

Thus treating misconceptions in desired contexts is essential and this effect appears to transfer to numerical questions (experiment 4) but not vice versa, (experiment 5).

COLLINS and STEVENS

Collins and Stevens are researchers interested in the application of the results of empirical studies of teaching and learning in artificial intelligence. In this article called 'A Cognitive Theory of Inquiry Teaching' they summarize the results of their investigations into discovery learning,(Collins and Stevens 1983).

Two limitations are noted :-

First they claim that discovery learning needs background knowledge of facts and concepts before the discovery process, say of some causal explanation, can proceed.Second they state that discovery learning is least appropriate for procedural domains such as arithmetic.

<u>Teachers attempting to enable discovery learning are concerned with two main goals.</u>

(a) teaching students particular rules or theories for which they have two subsidiary goals.
- debug students' incorrect hypotheses,
- teach students how to make predictions in novel cases.

(b) teach students how to derive a general rule or theory. For which teachers have four subsidiary goals.
- teach students how to ask appropriate questions,
- teach students the nature of the theory,
- teach students how to test a rule or theory,
- teach students to verbalize or defend rules or theories.

Inquiry teachers employ a number of strategies

- select positive and negative examples chosen to highlight relevant factors. Near hits highlight unnecessary factors, near misses highlight necessary ones,
- varying cases systematically, cf. Case,
- selecting counter examples,
- generating hypothetical cases to challenge reasoning,
- considering alternative predictions,
- entrapping students,
- tracing consequences to a contradiction,
- questioning authority,

All of which could provoke cognitive conflict.

A last strategy is more synthetic than the others.
- in testing hypotheses consider real world cases.

Inquiry teachers order of presentation

Select cases to :-

- illustrate more important factors before less important,
- move from concrete to abstract,
- more important and more frequent cases first before less important, less frequent cases.

Inquiry teachers consider

- errors before omissions (errors have more devastating consequences than omissions),
- prior steps before later steps (rational order),
- more important factors before less important factors.

COLLINS, SEELY BROWN and NEWMAN (1986)
This paper deals with the use of the apprenticeship role in teaching.

Apprenticeship involves context. School tends to decontextualize. Knowledge and learning are embedded in the social and functional context of use.

Schools are relatively successful in organizing and conveying large bodies of conceptual and factual knowledge but often this knowledge cannot be used flexibly. The flexible use of knowledge requires both cognitive and metacognitive strategies which are not usually taught. The authors believe that integrating these strategies with lower level knowledge is best taught following an apprenticeship model that emphasizes successive approximation to mature practice cf. medical education.

Apprenticeship involves a task in situ. The expert shows and the apprentice observes, followed by coaching with 'scaffolding', (i.e. various kinds of support) provided by the expert. A period of practice follows when the expert fades out of the picture.

Traditional apprenticeship, e.g. tailoring, involves a focus on the external and visible while cognitive apprenticeship involves cognition and metacognition. In order for cognitive apprenticeship to follow the traditional model these mental skills must be made external.

The authors have identified two basic means of fostering the crucial metacognitive skills.

- reflection on the differences between novice and expert problem solving. Alternation between expert and novice efforts and by techniques of 'abstracted replay' in which attention is focussed on key points of a student's work.

- the use of discussion, alternation of teacher and learner roles and group problem solving in order to both generate and evaluate ideas. Self-monitoring is encouraged as these social activities are internalized.

Maths is well suited to this approach having sparse conceptual and factual underpinings and requiring cognitive and metacognitive skills.

Two examples of cognitive apprenticeship are given. First the teaching of reading by alternation of roles by two children and second the teaching of college maths by group problem solving in which the teacher requires justification and explanations.

They propose a framework for designing learning environments :-

Content	domain knowledge
	heuristic strategies

	control strategies
	learning strategies
Methods	modelling
	coaching
	scaffolding & fading[3]
	articulation
	reflection
	explanation
Sequencing	increasing complexity
Learning	increasing diversity
	global before local skills
Sociology	naturally situated learning
	culture of expert practice
	intrinsic motivation
	exploiting co-operation
	exploiting competition.

KHANEY - HUMAN PROBLEM SOLVING AND INTERVENTIONS

This section is based on Khaney(1986), 'Problem Solving, a Cognitive Approach'. It is not a research paper or a review but it is a convenient summary of work on problem solving that indicates valuable interventions a teacher could usefully make.

Two kinds of problem are distinguished.

First, well defined problems where the initial state, the goal state, legal operators and operator restrictions are all given at the start, e.g. Towers of Hanoi. Solving this kind of problem involves transforming one state into another by use of the operators. Experience with one of these problems does not necessarily transfer to another well defined problem of a similar type unless people are aware of the similarity between the two and the second problem is simpler than the first. Awareness comes from the subject him or herself or by being told by another. (In the original paper, (Reed et al 1974), the author shows that transfer between similar problems occurred only when experimental subjects were told of the similarity, though practice did improve the ability to solve problems of the same type these subjects at least did not simply, by their own efforts, become aware of similarities between problems not of identical type.)

[3]Fading means the gradual removal of the teacher's support.

In particular, the simplicity of the target problem is promoted by :-

-making the instructions few and clear,
-making the number of mental steps required to solve the problem fewer,
-making the state space clear,
-making its relationships to the base problem clear.

Lack of transfer was demonstrated for homomorphic problems, i.e. where both problems are well defined but only similar since one, say, has more illegal moves than the other. (This is to be contrasted with isomorphic problems where the problems are essentially the same, as stated, but expressed in a different context).

Second, ill defined problems where it is not clear what the problem is, much less the solution. The classic example given is the 'many lines to a focus type of attack problem' which essentially concerns how to solve a problem by bringing a lot of power to bear at one point where it is only convenient to use many separate sources. The solutions are made imagining many rays or lines of power to cross at the point where the power is required. e.g. attacking a fortress by approaching inconspicuously from many different sides or attacking a tumor by bringing many separate beams of x-rays together at the site of the disease. In presenting the problem the goal states, legal operators and operator restrictions are only vague and have to be specified in much more detail for a doable solution. Thus the problems may be couched as attack the fortress without being discovered or use x-rays to destroy the tumor.

The results of these investigations are that the vast majority of people can only use analogy to (say) solve the the tumor problem after the fortress problem when given a hint that the two problems are connected, i.e. they only develop a general strategy for dealing with a particular type of problem (called a problem schema) or in simpler language make the analogy, after a hint. It can be expected that hints are more likely to be available in real world contexts than in experimental contexts.

Experience of a number of related problems can result in acquisition of a problem solving schema without a hint. This is especially likely to occur if two prior analogues are presented prior to checking for the schema and especially if the abstract solution principle is also presented.

Novices group problems as similar on the basis of surface features, experts use more fundamental principles.

Once an analogy is recognised, the problem difficulty depends on how similar the two problems are and whether the first solution is remembered.

Choosing the way to present problems may be important for revealing analogies, i.e.
- delete the inessential details,
- minimize differences,
- maximize similarities.

BROWN and CAMPIONE

In their paper of 1984 the authors discuss aspects of transfer that they are investigating. From the point of view of this report the main conclusions of interest are as follows:

1. Children can perform transfer in the same way as adults provided the problems posed are appropriate for their age group. Transfer is then often promoted by the right adult intervention. i.e. children can use knowledge flexibly if given the right opportunity.

   There is evidence that even very young children, 2 - 3 years old, can perform analogical problem solving provided the problems posed are appropriate for their age group. Known context is particularly helpful in enabling this, also hints and stating the rule applied.

   Everyday life is full of situations where transfer is mediated socially and very little problem solving left to the individual.

2. The ability to perform transfer with appropriate age related problems is a sensitive index of individual differences.

   In investigating how to promote transfer where assistance is not available the authors point out that it is essential to recognize individual differences which lead to variations in the ability to make transfers.

3. Transfer by children will be enabled if they are given :-

(a) training and practice in the context task-specific strategies (skills training)
(b) training and practice in the orchestration, overseeing and monitoring of those skills (self regulation)
(c) information concerning the significance and outcome of these activities, including where and when to perform the activities.

They recommend a method of reciprocal teaching (Palincsar and Brown 1984) which has been shown to be effective in helping children to read for understanding.

In this training is given for metacognitive skills such as :-
(a) considering the purpose of the activity,
(b) remembering relevant background knowledge,
(c) paying attention to important things,
(d) evaluating for consistency and compatibility with prior knowledge and common sense,
(e) monitoring your own comprehension,
(f) drawing and testing inferences.

The research leading to the conclusions reflects the influence of Vygotsky. Vygotsky believed that a great deal of development was mediated by social interaction in which children first experience a particular set of cognitive activities in the presence of others and only gradually come to perform these functions themselves.

First an adult (parent, teacher, master-craftsman,etc.) guides the child's activity doing much of the problem solving. Gradually they both come to share the problem solving functions with the child taking the initiative and the adult correcting and guiding where the child falters. Finally the adult allows the child to take over the major thinking role and adopts the stance of a supportive and sympathetic audience.

Thus initially the adult takes the leadership in the exercise of the skills acting as critic and questioner. In time these functions are partly taken over by the child who becomes, to some degree, self regulating and self questioning.

Vygotsky had the notion of zone of proximal development. This refers to the distance between the level of performance a child can reach unaided and the level of performance a child can accomplish when guided by another more knowledgeable in that domain.

For a certain child in a particular domain this zone may be quite small and the child may not be ready to participate at a more mature level than his/her unaided performance would indicate. For another child in that domain the zone of proximal development can be quite dramatically large, i.e. with aid, sometimes minimal, a child can participate much more fully and maturely in the activity than one might

suppose on the basis of unaided performance. In traditional terms these are notions of readiness.

In studies of transfer it is necessary to consider both unassisted transfer and that mediated by social interaction. All their work reflects the notion that transfer is often mediated by other people.

SCARDAMALIA and BEREITER

Scardamalia and Bereiter (1986 a and b), have begun an empirical study of 'inert knowledge', that is propositional knowledge that the student could express but cannot use. Their concern is that in school tasks the very way material is presented and learnt may lead inevitably to that knowledge being difficult to use in real life situations.

They distinguish between knowledge poor problem solving situations such as Towers of Hanoi problems and knowledge rich problem solving situations such as writing about 'my holiday'. They have chosen to investigate expository writing as an activity because there is likely to be a large amount of real world knowledge available to a child. Real life problems impose no limits on the knowledge that may be brought to bear. Such problems often give little idea of what knowledge may be relevant and the likelihood of giving a good answer will depend especially on the characteristics of one's knowledge and one's means of accessing it , ie. whether or not the knowledge is inert.

With children in elementary grades 'thinking what to write' comes as an enormous problem from beginning to end of the composing process and they will seize on any procedural device offered as a prompt. e.g. 'Another reason is ....', which has no domain content whatsoever. Whatever children did with the prompts offered the researchers were always struck by the local nature of the knowledge search. Indeed children, unlike adult expert writers, have difficulty in suggesting topics they might wish to use or not use for an essay before they start writing. That is they apparently could not access knowledge at a high level. This kind of searching is not normally required in conversation because conversation provides its own cues and because conversations are not planned. How might a child learn to access knowledge at a high level? If children are asked to propose a list of words they might use in their composition before they start writing it doubles the output of written words. Somehow, the authors believe, this process gets children to access their knowledge at a high level. However such a technique does not include selecting words for a particular purpose to help reach particular goals within the composition i.e. to write the essay with a particular result in mind, as a kind of

problem solving.

In older students, essays without consideration of the particular requirements of the question can result in the knowledge telling, goalless or scheme fitted form well known to teachers. Such a strategy is virtually worthless other than for certain kinds of school assignments, and is probably harmful to school work. Thus knowledge acquired in school may be constructed for knowledge telling and not for application ie. knowledge does not become interconnected as it is learnt or as it is used. The strategy develops as a result of teaching practices in which the material is analysed and taught by the teacher in a predigested form for the purposes of passing examinations or providing for knowledge telling answers as a way of getting students knowledge to flow. Thus students can reduce answering to relatively simple strategy of knowledge telling because it seems to work. This has great value for coping with school tasks that would otherwise exceed the student's performance limitations.

How are we to help children to improve their strategies for handling complex knowledge processing ? These authors research so far is well short of providing instructional prescriptions but they have identified two promising approaches discussed below.

1.FOSTORING THE DEVELOPMENT OF SELF-REGULATION IN CHILDREN'S KNOWLEDGE PROCESSING

Knowledge telling enables children to handle tasks which exceed their performance limitations. The trouble is that the consequences of such a deficient strategy may not be apparent (cf. rote learning for schoolwork).

In expository writing the goal partially emerges as you write, and there is a wealth of knowledge to choose from. Composition problems (ie. planning), are formidable obstacles when it comes to teaching someone better strategies for doing them. Since goals emerge as a child writes the value of planning is not clear since goals may change.

Strategy involving great detail (ie. algorithmic) is usually only possible in logico-mathematical problem solving, (cf. Case , this report). Outside this realm most intelligent activity depends on context sensitive rules e.g. grammar. In any tasks in which there is a large amount of propositional knowledge relevant choices of action became complexly contingent on the knowledge context.

Hence a more general level of strategy formation is needed involving heuristics. But this presupposes a metacognitive level for assessment and manipulation of

cognitive strategies. This in turn presupposes an existing executive strategy that is already highly developed enough to incorporate suggested new procedures.

The authors assume that it is not possible to build or rebuild a complex executive strategy through verbal strategy descriptions. ie. we cannot teach rules. They are convinced that the rules of task performance do not represent the most promising way of enabling students to use knowledge more effectively.

It is better to use self-regulating mechanisms e.g. checking, planning, monitoring, revising, evaluating as in Brown & Campione , (this report.) However the authors prefer a more fine grained specification than this. In their scheme each of their self-regulating mechanisms includes goal setting, knowledge retrieval, processing and storage operations.

Instructional methods aimed at promoting more mature cognitive strategies through the action of children's own self-regulating mechanisms .

These rely for their effectiveness on procedural facilitation. This consists of routines and external aids designed to reduce the processing burden involved in bringing additional self-regulatory mechanisms into use . It is assumed that the child already has some way of dealing with the task which is to some degree satisfactory, then at least a child cannot say s/he does not know how to do it (for logical or practical tasks it is quite possible that a child could easily say s/he cannot do it). The instructional goal is to introduce an additional self-regulating mechanism. Normally this will inevitably increase the processing load so that children forget to self-regulate. Procedural facilitation provides special supportive procedures that (a) provide cues or routines for switching into and out of new regulatory mechanisms while keeping the executive procedure to which they are added intact and (b) minimize the resource demands of the newly added self-regulatory mechanisms.

The main steps in designing a procedural facilitation are to :-

(a) Identify the expert self-regulatory function.
(b)Describe it as explicitly as possible. e.g. revision of a passage involves comparing, diagnosing, choosing a revision tactic and generating alternatives prior phrasing and structuring text.
(c) Design a way of routinizing the onset and offset of the self-regulating process that makes minimal demands a mental resources. e.g. initiate routinely at the end of every sentence.

(d)Design external supports on teachable routines for reducing the information processing burden of the mental operations. e.g. to facilitate comparing and diagnosing one may offer a limited set of alternative evaluations such as, 'people may not understand this point'.

The analysis produces a much simplified version of the self-regulatory function.

At the end we need to test whether the particular method of self regulation can be applied in in a more complex situation. (Initially avoid high level problems and those that can be answered mechanically.)

Most children claimed this example of procedural facilitation enabled them to work more easily. They would do it at the end of each sentence and they made more revisions than usual.

In procedural facilitation the burden is not taken off the child by removing parts of the self regulatory method as a teacher might easily do rather a simple framework is provided in which the child does most of the work.

2. CONCRETIZING GOALS

A few children used the procedural facilitation as a way tackling higher level goals but many used it to make the job easier i.e. to cue what to say next. Procedural facilitation cannot directly affect knowledge telling but to help them decide on goals they suggest concretizing them as is often done in maths teaching e.g. concretizing subtraction using Diene's blocks. In this form of concretizing the logical equivalence of blocks and symbols is demonstrated, in compositional tasks we are looking for psychological equivalence.

Characteristics of goals in compositional tasks

- they are global but the end state is not usually specified,
- success is not usually all or none,
- a desired end state emerges,
- goals may be revised.

In attacking the global goal there two approaches are suggested. Either approach the goal by continuous reassessment of what is needed or avoid goal constraints and take each step based locally on what has been written already ie. always move forward without reconsideration of the problem to be solved. Children often follow the second course. To try and get them to follow the first the authors tried concretizing goals. The children were given an ending sentence to specify the global

goal and then asked them to compose to it. This approach does stimulate goal seeking. The authors also tried to get children to specify their own concrete goal, e.g. the goal of realism implied by a question is replaced by the concrete goal of producing a fictitious narative that will pass for a true account but the child decides exactly how to do it.

Goal construction

The authors are experimenting with this in terms of the procedural facilitation of planning. Progress has been made by using thinking aloud in class.

RESNICK

A number of studies by Resnick and her students involve interesting work on the teaching of arithmetic in addition her work appears to be increasingly embracing the constructivist view of learning.

In Resnick and Omanson (1987), the authors are concerned with how understanding may enhance procedural skill in place value and subtraction exercises.

The study concerns mapping a blocks representation of multicolumn subtraction to a written numerical representation. The children tested demonstrated a much better grasp of quantity conventions in the block representations than in the written representations. Explaining the mapping between the two only moderately improved the children's ability to perform written subtraction correctly in a post test despite the fact that they could still explain why their former bugs were incorrect. Analysis of individual performance suggests that the sheer amount of talking, especially verbalization about correct procedures, by a child about what s/he is doing is important. Most interestingly, the child's initial level of understanding of the manipulation of the blocks and mastery of the mapping routine did not predict who learned.

The authors argue that a commentary by a child on his/her correct procedure produces learning probably because correct verbalizers are attending more to the quantities involved in borrowing etc. and are frequently rehearsing correct statements about place value.

Frequent questioning by the experimenter is an acceptable way to get a child to verbalize more which suggests that teachers can play a very active role in directing a child's attention to the quantitative meaning of arithmetic notations.

Despite the fact that it is the quantitative aspect that is crucial, the mapping procedure is believed still to be valuable because it helps to develop an abstraction that encompasses several representations in which the same result is derived by different routes. The expanded notation for algorithms may be equally useful here.

However, even the high levels of understanding may not reliably eliminate bugs. This may be because they are part of automatized procedures which suggests it is important not to let bugs develop to this point. Hence some of the value of promoting understanding from the very beginning in order to block the emergence of bugs.

DENVIR and BROWN

In Denvir and Brown (1986 a and b) the authors report a descriptive framework of the simple arithmetic skills of low attaining 7 - 9 year olds and a diagnostic instrument based on it. The knowledge of individual children fits the framework quite well and it can thus be used as a basis for teaching. Children were taught both individually and in small groups (through group work proved most effective). However, although the pretest knowledge of individuals is useful information it is not a predictor of what or how much will be learnt. In particular there was no relation between pre-test level on the hierarchy of skills and the number of gains made. The stronger predictor of the number of gains seemed to be the child's involvement in practical tasks and discussion and the degree to which the child regarded the work as consisting of acceptable mathematical tasks.

SMALL GROUP INTERACTION

Cooperative problem solving with computers is of undoubted importance. When children use computers in the classroom they often work in small problem solving groups. Cooperative problem solving is also being actively promoted in schools as a way of encouraging flexible thinking and reducing rote learning. The central importance of group work with micros has recently been focussed on a recent conference (Lewis 1986).

Much of the advantage of co-operation appears to arise through discussion. In conversing learners may have to lay out their beliefs, explain themselves, receive criticism, expose errors, confront difficulties, etc.; acts they may well not perform by themselves. For many the social interaction is highly motivating. When computers are part of the problem situation a central idea is that human conversations can obviously be far richer than any human-computer dialogue we can presently support. In addition, as will be seen in the summaries below, computers can facilitate cooperation.

Note, small groups are generally taken to mean 2-4 people.

General Conclusions

These are general conclusions which I believe can form a tentative basis for thinking about children working in small groups with micros.

1. Many children find that working with others motivates their interest in problem solving.

2. Cooperative work with the computer is natural. That is, we can expect children to want use computers cooperatively.

3. However best results will be obtained if teachers show children how to organise cooperative work and pursue it with them over a long period. Work should involve mutual action with equality of participants and group accountability. A division of roles may be useful and individual accountability can be combined with group accountability.

4. Learning in small groups is most effective when gaps in understanding between individuals are neither too 'great' nor too 'small'. The work itself must also be at the appropriate level of difficulty. Gaps between understandings have the potential to reveal dissonant points of view (ie. cause cognitive conflict) which may be resolved by discussion and reflection.

5. In resolving dissonant points of view the starting and end points for individuals are personal thus tending to promote individual differences.

6. Interaction often involves discussion but observation of another's actions is also important.

SUMMARIES OF THE MAIN PAPERS OF INTEREST

JOHNSON and JOHNSON

These authors have been publishing on co-operative learning and how to organise it for at least a decade. In their most recent paper (Johnson and Johnson 1986) they have published their conclusions regarding co-operative learning and the micro. The age groups referred to vary between pre-school and 13 years. (Cummings (1985) also has some interesting details on the micro and cooperation.)

How students should interact with each other while working with a computer is relatively ignored. Yet how teachers structure student-student interaction patterns has a great deal of influence on how well students learn and on their attitudes to school, to subjects, towards each other, towards computers and on their self esteem.

There are three basic ways students can interact with each other as they learn. Competitively, co-operatively or individualistically (i.e. no interactions).

Groups must be shown how to work co-operatively to get best results and this may take time. In a co-operating group individuals take responsibility for each other's learning and the success of the group as a whole is the goal. In such groups labour, leadership, resources and roles may be divided. Individuals collaborate through communication, trust and sorting out arguments.

Co-operative learning with computers is contrasted with individualistic learning with computers. (No doubt similar contrasts apply when computers are not present.)

- individualistic learning can create a sense of social isolation,
- individualistic learning denies learners the opportunity to summarize and explain orally,
- computers cannot provide social models for imitation or comparison.

Peer modelling (ie. observation) is one of the most potent methods of teaching learning skills and strategies and is especially effective with difficult material and when students are learning to use a computer.

- a computer is not as potent a reinforcer as the encouragement and approval of peers,
- computer feedback is much more limited than feedback from peers,
- individualistic learning limits the amount of creativity students apply as compared with co-operative groups.

Similar effects are found when competitive and co-operative learning is contrasted.

Evidence is drawn from a number of sources to show that students prefer to work co-operatively at the computer as compared with working on tasks without a computer.

The authors state that co-operative learning and computer assisted instruction are complimentary since computers can carry out many of the low level functions of the learning activity such as controlling the flow of activity, monitoring results, and choosing new activities. This enables students to be more involved in more difficult activities such as discussion and problem solving. Several examples are given of co-operative learning with a computer.

Examples of roles used in these activities included keyboarder, explorer, knowledge specialist, recorder, checker, encourager.

Students are shown how to alternate roles, structure goals for co-operation, and evaluate co-operation.

In this paper (details in an earlier one, Johnson and Johnson and Stonne (1985)), the authors state that competition is particularly unfavourable to girls but that co-operation (at least in mixed sex groups) is much more positive for girls' learning.

MIYAKE

Miyake (1986) considered the process whereby two people interact to understand how a sewing machine works. Similar, but so far not so interesting work is being done in relation to understanding operating systems (O'Malley et al 1984).

Understanding a sewing machine is extremely difficult. The experimental situation encourages co-operative explanation of the mechanism and the discussion reveals

something of the thinking involved in trying to understand the machine. The process of understanding involves working 'downwards' gradually refining and understanding of functions and the mechanisms that enable the functions.

This paper is of interest here because it reveals more of the co-operative process and although it involves two adults engaged in a difficult task there are a number of similarities to work with co-operating children working on Piagetian tasks, Perrot-Clermont (1980). It suggests, albeit at a gross level, how individual differences continuously arise and it indicates the sort of gap in understanding that might be sufficient to provoke cognitive conflict. If gaps and the provocation of conflict and resolution could be observed in children learning in co-operating groups then such knowledge might be added to educational software to help that learning.

In the process of understanding, subjects cycle a number of times between understanding and non-understanding.

Understanding follows a pattern of mechanical function identification in the sewing machine, followed by questioning the function followed by searching for the mechanism by which the function is achieved. A mechanism is first proposed, then criticized and then confirmed. Then the cycle is repeated as a new function as part of the mechanism understood is identified.

In identifying, proposing and confirming there appears to be understanding while, in searching, criticizing and questioning people feel they do not understand.

Understanding took a long time and went through about 30 steps in each understanding session.

The process of understanding was characterized by frequent imaginary shifts in the direction from which the machine was examined, e.g. shifting from imagining the movement of the needle from above and then shifting to imagining it from below.

As pairs work together and individuals generate solutions, these solutions are subject to mutual criticisms or what can be called validation checks. However this does not mean that at the end both members of the pair have the same conception of how the machine works. Rather beginning and end understanding is personal but criticized. The criticism is important as self criticism is relatively rare and the personal solutions are important because it shows the individual differences will tend to be promoted.

Interestingly, most criticism occurs from the person with least understanding and should probably be thought of more as a complaint though it does force the other to keeping searching for a satisfactory mechanism. Most criticism occurs when the pair are at different levels of understanding of the functions of the various parts of the machine; relatively little criticism occurs when both partners are on the same functional level. The functional levels are those suggested by the analysis of protocols and cannot be justified in any other way in relation to other possible divisions of functions.

Partners tend to assume the roles of observer or leader. The observer role is associated with more divergent thinking and new ways to understand the machine, e.g. a suggestion to take the sewing machine to pieces. Leaders engaged in more local focus and tended to concentrate on new but local ways to deal with the current topic which did not usually change the general course of the discussion.

HOYLES and SUTHERLAND

Hoyles and Sutherland (1986) reported an examination of peer interaction when learning LOGO. They view peer interaction as complimentary as opposed to conflicting; they claim the latter type of interaction is suggested by Piagetian framework of cognitive conflict. (Its not clear to me why this is so.)

They understand the style of interaction along several dimensions.

Careful planning <-------> open ended investigation

Global focus <-------> local focus on detail

Systematic <-------> not systematic

In the early stages in one pair most of pupil talk is specifically focussed on getting the task done and little attempt is made to explain or convince, though this did develop over time.

Other factors crucially influence the nature of interaction :-
- nature of task ,(abstract/real world),
- extent of local/global planning,
- extent one partner became more dominant or talkative,
- extent of agreement on strategy,
- extent of getting on socially.

Nevertheless problem solving was helped by articulation, arguing, explaining and listening as well as observation of screen output, but progress was not guaranteed.

Note , groups were not taught how to work co-operatively.

PERROT-CLERMONT

Perrot-Clermont (1980), an author from the Genevan School which continues Piaget's work, focussed on learning in Piagetian tasks e.g. conservation of liquid, number, length etc. in children aged 4-7. The experiments revealed cognitive changes in children after social interaction.

If a process of imitation is used to explain the effect of social interaction it does not allow us to understand why individuals with less advanced behaviour are not imitated by those with more advanced behaviour. We have to understand why novel behaviours are produced by more advanced subjects interacting with less advanced ones or by less advanced acquiring the advanced behaviours but producing novel arguments to justify them.

The explanation offered is that although a social model is a source of cognitive change for the subject the model does not provide a form of thought to imitate. Rather the model stimulates the development of a child in a natural direction of development. The explanation predicts that the effectiveness of the model will increase with the opitimization of the gap between the developmental levels. The gap needs to be small enough so that difference in behaviours corresponds to the cognitive acquisition the child has to make, yet be large enough so that contradiction between two sets of behaviours creates cognitive disequilibration in the subject.

Disequilibrium occurs due to a conflict between points of view. It stimulates an activity of accommodation in which the child is confronted with his or her own reactions and those of the model.

Most interactions in the experiments were found to be co-operative though no specific training for co-operation was given.

DOISE and MUGNY

These are also authors from the Genevan School. Their book, summarized here for the special needs of this report is called 'The social development of the intellect'. It is an exposition of a partially developed theory of the social nature of the intellect which they call socio-constructivist. Most of the results are due to the work of their group in Geneva. Most of the experiments involve conservation or orientation

tasks with children between the ages of 5 and 8. These experiments are all designed to make social interaction unavoidable.

The results presented are not only of importance in understanding learning but they suggest specific principles which can be used for the design of computer based learning activities.

The essential idea as seen from the point of view of this report and as proposed and justified by the experimental results is that certain social organisations in small groups have much more potential for promoting learning of the kind shown in the experiments than others, including individual learning. The most successful organisations work because they produce cognitive conflict which imposes a barrier to social relations which in the specific situation can best be overcome by resolving the conflict rather than by some form of compliance or acceptance of ambiguity. That is to say , for the child , the motivation is not to solve the experimental problem but to find a way to enable the smooth running of social relations. As a result of this conceptualization and to distinguish it from cognitive conflict occuring in an isolated individual they call their theory one of socio-cognitive conflict. However, they do not propose a sharp differentiation between the two but rather cognitive and social poles of the overall development of the intellect.

Socio-cognitive conflict works where experimental tasks that create cognitive conflict in individuals produce no effect whatever because the social situation requires, indeed forces discussion in order to resolve the conflict. In the individual case, even if the conflicting situation is noticed the correctness of the new suggestion can always be denied.

Specifically, learning is reduced by hierarchial social groupings of peers, by adult teaching and, in general, by situations where disagreement can be suppressed (or is at least only weakly present). In contrast social groupings which promote learning are where disagreement is strong. Examples are disagreements between equals or more complicatedly between two adults with different incorrect points of view and a child called upon to resolve the problem after observing their disagreement.

Learning is further promoted where the experimental task is set in a context where social concepts such as equal shares, or shares in proportion to body size relate to the task. (The causal link between the two is unclear and is an important area for future research.) Here new cognitive structures clearly serve to establish or maintain social relations.

Although social groupings with high socio-cognitive conflict can promote learning the effect can only be seen for a particular task when children are both judged to be ready to learn the relevant concept and have not already completely or even partially learnt it. (The importance of timing here can explain why so many experiments in group work produce unclear results.) One important prerequisite is in any socially oriented task is the ability to see things from another's point of view. Since progress depends not on the elimination of one understanding by another but the conscious grasp of the differences between your own understanding and those of others.

This is not to say that mere observance of a correct model does not contribute to learning. However this contribution depends on the extent to which the correct model gives rise to socio-cognitive conflict. To be effective the model must introduce an opposed understanding and at the same time offer to the thus confronted child important elements for the reorganisation of his or her ideas.

It is important to note here that the presence of an adult is used as it is necessary to ensure good communication and the understanding of the task. It is also important to point out that at least in some primary school classrooms the same has also been found to be the case (Desforges and Cockburn 1987, pps 151-153 and elsewhere). The difficulty is that while children of these ages have potentially useful communications they can make to each other about maths they cannot sustain a conversation about the subject without the help of an adult so that little discussion takes place in groups of children without a teacher.

One of the central experiments is particularly noteworthy because it highlights both an important point that is being made by the authors and an important point they are not making.

In this experiment the effect of socio-cognitive conflict in learning to conserve is examined in a three test experiment. In one no discussion between the children who are tested individually and the experimenter is allowed and it is found that no progress is made by any of the children. In a second test the experimenter and a collaborator behave as non-conservers and disagree as to which situation is the 'most'. Progress to conservation is made by some children here although the adult suggestions are both incorrect and at the level of non-conservation. In a third test the correct solution is presented to the children by the adult and the most progress of all is made and many justifications offered by the children later are different from those of the adult.

Since the children in the last experiment often offer their own justifications progress in those cases at least, is not just a question of imitation and straightforward teaching does produce progress. In at least these cases some kind of conflict has occurred in a straightforward teaching situation. Thus this kind of teaching is not excluded as a method of learning and as a method of provoking conflict. However the second experiment shows how new understanding not originating in the adult can be constructed by a child, albeit overall, in the absence of the correct explanation supplied by the adult it is perhaps not as effective in some cases. In subsequent experiments the authors show how even retrogressive behaviour by an adult can still produce progress in children. These later two cases clearly show how construction of new understanding can occur but they are not necessarily advanced as the way to achieve most learning or as the most appropriate way to teach in a given circumstance.

LIGHT and GLACHAN

Light and his co-authors are amongst a number of British workers interested in small group work with computers. In a paper in 1985 (Light and Glachan 1985) they discuss the facilitatory effects of interaction between children of similar initial ability. They point out that Doise's work has been criticized and suggests that this latter analysis may be more appropriate to goal directed problem solving tasks, where it can be assured that the parties involved agree about the desired ends, while frequently having differing views about the most appropriate means. This idea forms the basis of the paper.

Their experiments involved children solving Towers of Hanoi problems and playing Mastermind. Working together in pairs can significantly facilitate subsequent individual problem-solving performance and this applies as well to 12 year olds as to 7 year olds.

Mastermind elicits a high level of verbal interaction but Towers of Hanoi does not, yet both situations facilitate individual work. In Glachan and Light (1982) the authors venture the opinion that where there is a relative abscence of verbal interaction the advantage of working together in a joint endevour occurs if a child with one strategy in mind has to consider the alternative moves of the other child when each joint move is decided upon.

They stress the importance of the joint nature of the tasks and that steps must be taken to avoid dominance by one of the pair, and to pitch the level of difficulty correctly. The authors caution that these studies do not provide a basis for assuming that truly collaborative group work will provide an educational panacea.

However there are significant potential benefits and they should be explored.

WEBB

The most recent review of research on small group learning in general appears to be is that of Webb (1982). The conclusions are fairly sparse but worth noting.

Giving and receiving help is beneficial for achievement. Help is best provided only when requested and in the form of an explanation rather than indicating simply whether an answer is correct or not. Explaining is especially advantageous in promoting understanding by the explainer.

Group rewards promote helping behaviour and may be necessary for co-operative learning.

DAVIDSON

Davidson (1985) reviewed selected research in small group learning on teaching in mathematics.

He describes the group activities as follows:-

'The various small-group learning procedures have in common the following basic notions. First, the class is divided into small groups, of two to six members apiece. Each group has its own working space, which may or may not include a section of the blackboard. Each group is involved in discussing mathematical concepts and principles, in practicing mathematical concepts and principles, in practicing mathematical techniques, and in solving problems. The teacher moves from group to group, checks the students' work, and provides assistance in varying degrees.'

His main conclusions are :-

'Considering all the studies comparing student achievement in small-group instruction and traditional methods in mathematics, the majority showed no significant difference. When significant differences were found, they almost always favoured the small-group procedure. Only two studies (Loomer, 1976; Johnson et al., 1978) provided limited partial support for the superiority of the control procedure. No evidence showed that either small-group instruction or the control procedure was superior in fostering the learning of higher order concepts and principles or the solution of nonroutine problems.

If the term achievement refers to computational skills, simple concepts, and simple

application problems, the studies at the elementary and secondary levels in mathematics support Slavin's (1983b) conclusions: (a) "Cooperative learning methods that use group rewards and individual accountability consistently increase student achievement more than control methods in ... elementary and secondary classrooms" and (b); "Cooperative learning methods that use group study but not group rewards for individual learning do not increase student achievement more than control methods" (p. 443).'

In the details of results he frequently stresses the clear value to learners of explaining to others (and the probable, though less clear value, of receiving explanations). Most of the work reported in this context is also reported in Webb (1982).

SLAVIN

The report by Slavin (1985) highlights some of the problems of co-operative learning in general and mathematics in particular.

The specific interest here is in combining individualised and co-operative learning in order to avoid the problems of pure co-operation.

In pure co-operation there is a problem of individual accountability. It is important that every group member sees that they must contribute, indeed this is necessary for success. Hence the provision of individual scores which contribute to the group score or the taking of separate roles.

Because of the differences in ability in students, instruction at a single pace is bound to leave some of them behind while holding others back. Further, because maths builds on a hierarchy of skills there is less or no opportunity to start again and so once a student drops behind it may have a permanent effect. The problem is typically tackled by teachers, by slowing the pace of teaching for the whole class.

There may be limits in the ability of co-operative learning methods to meet these problems of student heterogeneity.

Slavin describes a team assisted instruction approach as a means of combining the co-operative learning and individualized instruction. Essentially teams of 2 or 3 work individually but check each others answers and provide help for each other. The results are reported for 8 - 11 year olds learning basic maths. These results were good, but often pure co-operative and pure individualized instruction was as good. Group teaching by the teacher at appropriate times was essential.

GREIF

Greif 1986 gives an interesting example of learning to use a computer by means of a co-operating small group. The author highlights the value of deliberately creating the opportunity for error with subsequent discussion .

KELLER

Under the heading of relevance Keller (1983) considers important personal values that are motivating. Two of a more social nature, not included in the first part of this report of crucial literature are power and affiliation.

Power is a process of exerting influence and affiliation needs may be in conflict with power needs. However there is no need for both to be satisfied simultaneously and both may find expression in co-operating groups.

The heuristics suggested fit in well with Johnson and Johnson.

- to make instruction responsive to the power motive, provide opportunities for choice, responsibility and interpersonal influence.

- to satisfy the need for affiliation, establish trust and provide opportunities for no risk co-operative interaction.

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